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A comparative analysis of the wind load distribution on the lenticular structure

I S Inzhutov[1], Q S Yang[2], V I Zhadanov [3], S P Amelchugov[1], P P Melnikov[1] and I V Melnikova[1]

[1]Siberian Federal University, 82 Pr. Svobodny, Krasnoyarsk, 660041 Russia
[2]Chongqing University, School of Civil Engineering, China , 400044, No.174 Shazhengjie, Shapingba, Chongqing
[3]Orenburg State University, 13 Pr. Pobedy, Orenburg, 460018 Russia

muller.pp@mail.ru

Abstract. Global changes in climate conditions in the Arctic region result particularlyin the increasing strong and long-acting winds. This determines the need to reduce pressure on buildings and structures, for example, through the use of streamlined shapes, as well as refinement in the design of wind impacts and, accordingly, a more adequate model of the wind loads distribution on the surface of the building. In connection with the last point, the authors have conducted a comparative analysis of the wind load distribution by the lens-shaped (lenticular) building case.

1. Introduction
Building structures are exposed to various loads. One of the most significant loads is climatic effects, namely snow and wind. According to the research of meteorologists, the climate on our planet is constantly changing due to various factors. A set of regulations [1], on the basis of which all calculations are currently made takes into account climate impacts. All data in this set are based on meteorological observations made before 2010. According to the latest meteorological and climatic studies [2-4], it can be noted that over the past 8 years the climate of the planet has changed.

The map of the wind pressure zoning made almost 50 years ago in the existing regulations [5] and it is still used with small changes. A significant part of the territory is assigned to poorly studied areas and the values of wind speeds are not presented. Generalization of accident materials and results of field surveys shows that to ensure the reliability of the frame and arches structures in the northern territories, we need scientifically grounded formulation of regulatory requirements for snow and wind loads [6].

The desire for unification in the domestic norms leads to the fact that the snow loads regulation in one snow area includes areas with a very large spread of snow loads due to the interval parameters gradation. According to the weather data in some regions of Yakutia, annual snow maximum exceeds the calculated values of the snow cover weight on the ground according to building standards by 1.5-2 times [6].

The main aim of this research is to correct methodology data for calculating wind loads on buildings and structures with nonlinear forms in the Northern regions, with the subsequent development of a mathematical model for distributing wind loads on the surface of buildings of the dome type.

To achieve this aim, the following tasks are set:

- to compare the normative values of the average monthly outside air temperatures with the actual outdoor temperature data for the last year;
- to conduct numerical researches on the chosen type of building in accordance with the active Set of Rules and computational complexes.

2. Problem setup

Norilsk was chosen for the design of the lens-shaped building. The city belongs to the sixth snow area, and the fourth wind area [5].

It is required to determine the daily, monthly and annual averaged outdoor temperature, absolute pressure and relative humidity as part of the work for the necessary comparison with the regulatory data.

Determination of the monthly averaged value of the outdoor air temperature is made by the formula [2] using the data from meteorological stations of Krasnoyarsk northern territory.

Calculation of wind pressure is made according to the formula [1]. The data obtained from the meteorological stations [2-4] are presented in Table 1.

Table 1. Outdoor temperature, ^{o}C.

Mon.	Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Average value of temp.
Temp.	-28.16	-24.87	-16.42	-8.84	-1.81	-1.81	10.49	16.51	3.91	-8.32	-21.87	-21.32	-7.53

Table 2 show standard values of average monthly outdoor air temperatures according to [1].

Table 2. Standard values of average monthly outdoor air temperatures, ^{o}C.

Mon.	Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Average value of temp.
Temp.	-28.20	-27.30	-21.90	-15.30	-5.60	5.80	13.70	10.90	3.80	-8.50	-20.60	-24.90	-9.80

The results obtained indicate an increase in the average monthly outdoor temperature throughout the year by standard values of average monthly outdoor air temperatures, with a maximum deviation of 6.5 ^{o}C.

It should be noted that there is a trend of temperature increasing by approximately 2.3^{o}C. This factor is especially important when designing the unprotected building structures such as bridges and pipeline supports, and these climatic effects must be taken into account.

Based on results of [2-4] and the calculations made according to [1], we prepare Table 3 that presents data on the wind pressure for Norilsk on a monthly basis.

Table 3. The wind pressure for Norilsk, kPa.

Mon.	Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Average value of wind pressure
Pressure, kPa	0.84	0.83	0.80	0.77	0.75	0.72	0.70	0.72	0.74	0.77	0.82	0.81	0.77

According to [5] the standard value of the wind load for Norilsk is 0.48 kPa. The results presented in Table 3 exceed those given in [5] by 0,34kPa.

Comparison of the normative and calculated values of the wind loads allows noting the tendency of increasing climatic loads by 5.2 %. It is advisable to perform calculations using the SCAD and ANSYS software for further analysis of the impact of wind load.

3. Methods of computations

First, the calculation of the wind load was carried out with the load values calculated according to [5]. In all cases, the standard value of the wind load W is determined as the sum of the average Wm and pulsating Wp components [5].

The chosen scheme for the building calculation is given in Figure 1. Here l=30 m, f = 5m, h1=7m. The dashed line indicates the true shape of the designed building. Red line indicate the shape of the building, which cannot be calculated according to [5].

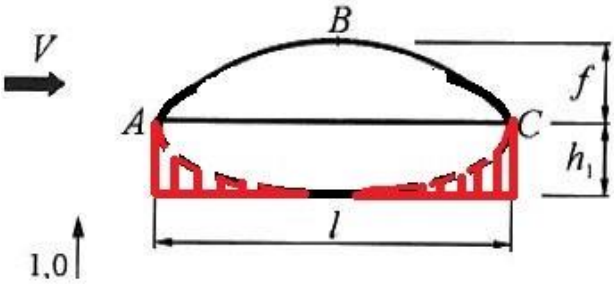

Figure 1. Round plan building with a dome cover.

According to [5], the lower part of the building shown with red line in Figure 1 is not simulated which can result in serious distortions in further calculations. Based on these calculations we have the wind pressure at points A, C and the BB, which are shown in Table 4.

Further, the computations were performed using software complexes ANSYS and SCAD with the loads corresponding to the selected region. ANSYS Fluent module was used to compute the external flow (license number 501758).

The size of the computational domain for wind load calculation is 100x80x40 m. The position of the center of the model in the stream is: from the entrance area is 40m; from the exit area – 60m; from the side edges - symmetrically 40m; the model is raised to a height of 2.9 m above ground level 5050.

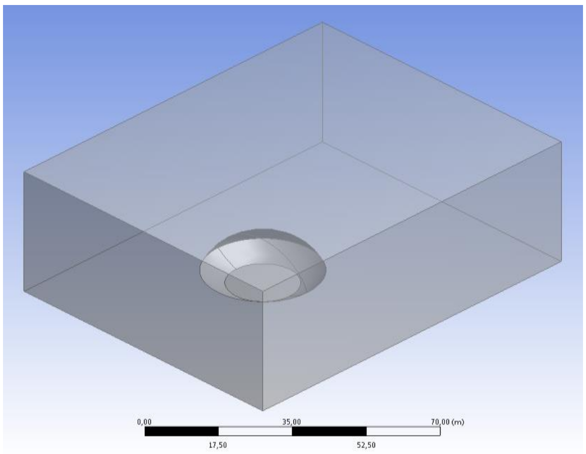

Figure 2. Computational domain for wind load calculation in ANSYS Fluent.

Grid of tetrahedral type is used without refinement to the walls. Flow data are as follows air with density 1.225 kg/m^3, viscosity 1.7894 ·10-5 kg/m·s. Flow velocity at the inlet is 5 m/s. Monometric pressure at the outlet is 0 Pa. The boundary layer was not taken into account. The flow was considered to be laminar.

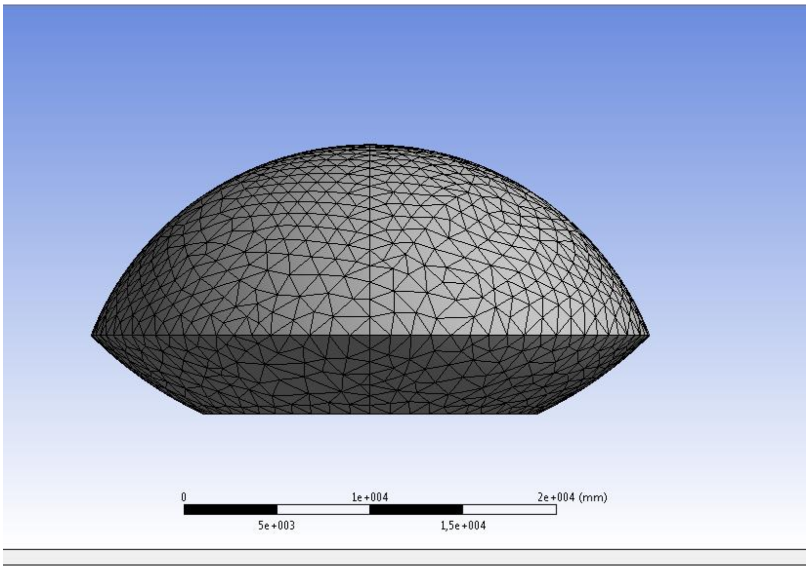

Figure 3. Geometry with a calculated grid.

To study the stress-strain state, SCAD software was used (license number 13263). The arch was divided into 6 equal parts, one of the sections being further subdivided at the intersection with the rack. Previously, the area of the 190 × 825 mm upper arch consisted of pine lamellas was used. In the lower arch, the cross-section is 193 × 190 mm. Figure 4 shows the designed building in a plan with a wind direction used in the calculation in various software complexes.

When analyzing the stress-strain state of the arch, two different variants of loading were considered:

1. Self-weight of load-bearing structures including floors. The load is uniformly distributed along the length of the arch, the value of the loads from the weight of the enclosing structures is collected along the width of the cargo space-the arch step was 6 m. The internal mass of the bearing elements of the arch is assigned with the help of internal SCAD tools based on the previously assigned sections of the elements;
2. Wind loads.

One of the important conditions that determine the work of rod structures is the consideration of the real work of the connection of elements, since the compliance of the joints of rod systems has a significant impact on the stress-strain state of the structure in whole. To take into account the compliance of the nodal joints of the arches, calculations were carried out in 2 stages.

In the first phase, forces and deformations were determined without taking into account the ductility in the nodal joints, and in the second phase, taking into account the ductility of the joints in accordance with recommendations.

To account for the deformability of connections, finite elements in the areas of joint connections have been provided in the design scheme, for which conditional modules of elasticity were introduced in the second phase.

4. Results

Figure 5 shows the wind pressure isobars, determined by the calculations of the building under the study. Red lines shows the results obtained with the SCAD software, blue lines correspond to the results obtained with ANSYS software.

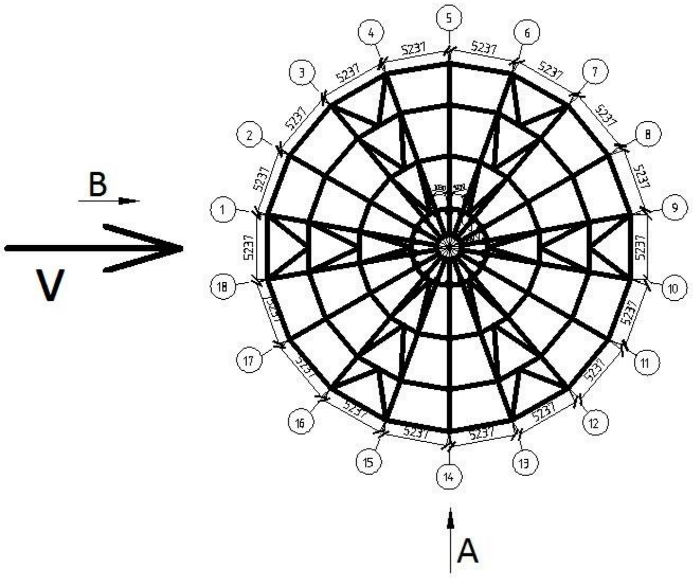

Figure 4. The designed building in the plan.

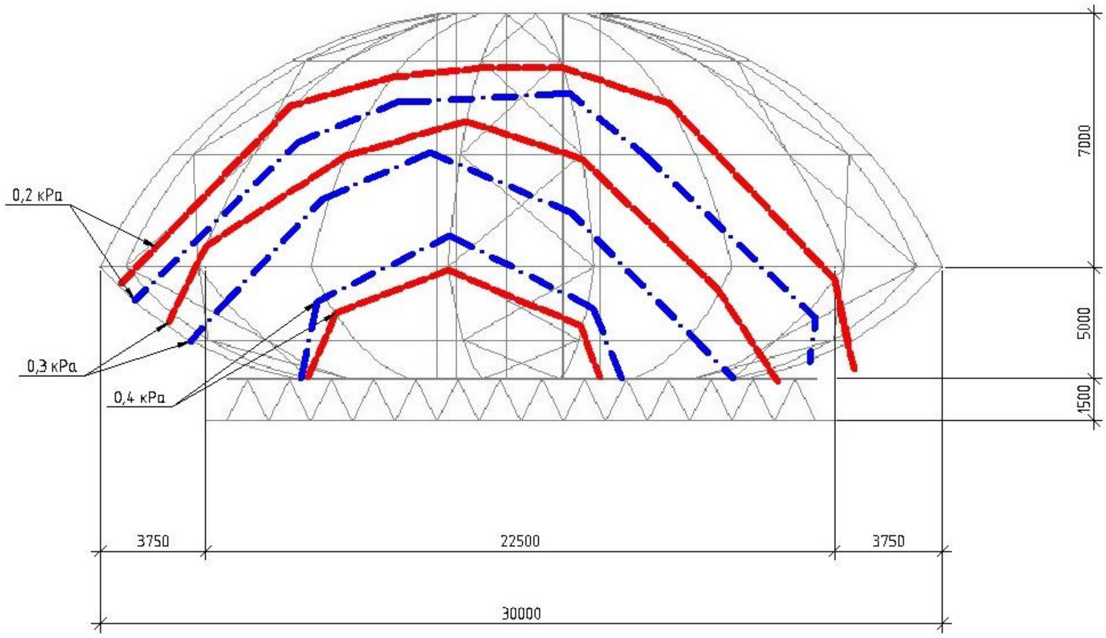

Figure 5. Values of the wind pressure distribution obtained using SCAD and ANSYS software.

The results of the wind pressure calculation in three investigated points are summarized in Table 4.

Table 4. The wind pressure values at various points.

Point	Data [5], kPa	SCAD, kPa	ANSYS, kPa
A	-0.32	-0.438	-0.46
BB	-0.24	-0.114	-0.18
C	-0.1	-0.291	-0.3

As it can be seen in Table 4, the obtained values for the three points of wind pressure differ from each other, depending on the chosen calculation technique. For comparison, the result obtained in ANSYS and [5] diverges by 30%. The result of calculation in SCAD and in ANSYS differs by 6%.

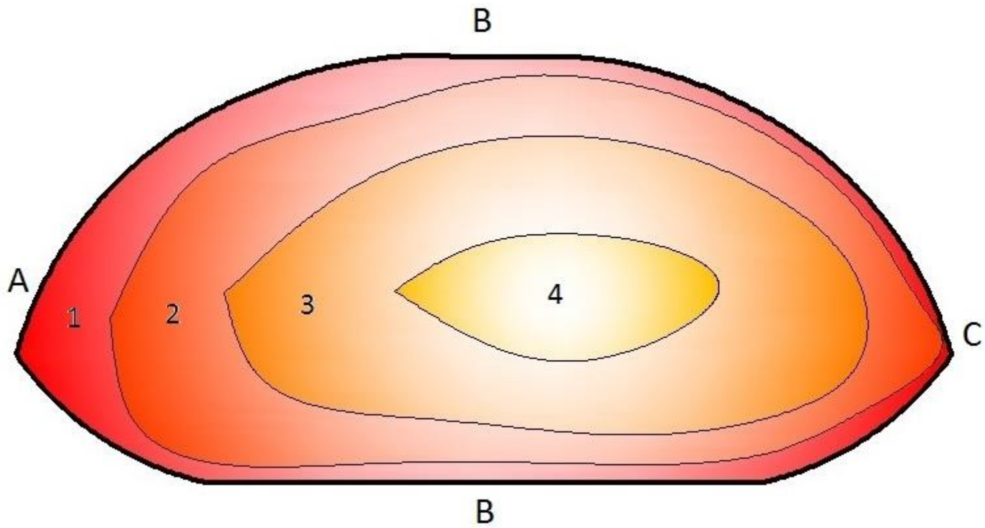

Figure 6. The wind pressure field on the building cover calculated in the SCAD software, 1-0.438 kPa, 2- 0.375 kPa, 3-0.21 kPa, 4-0.11 kPa.

Starting from the data presented in Figures 6 and 7, the wind pressure field on the building cover is different, which leads to the need to conduct studies on other complex buildings, representing combinations of dome shapes for further clarification of the wind load distribution.

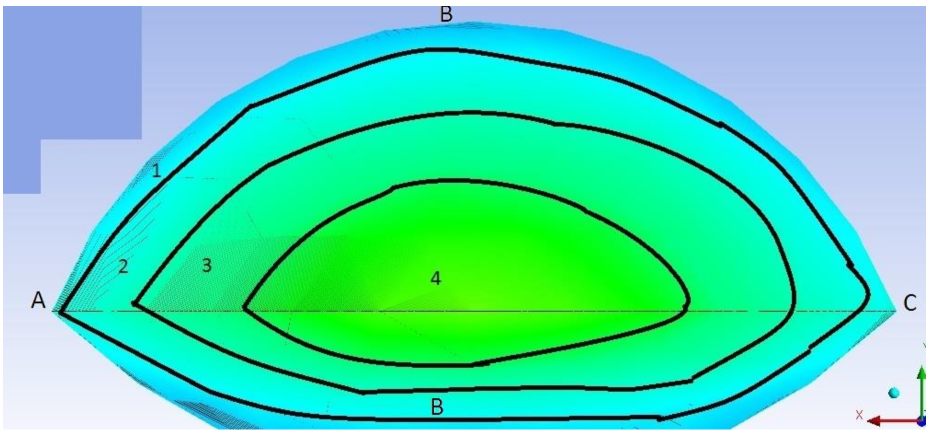

Figure 7. The wind pressure field on the building cover calculated in the ANSYS software, 1 stands to 0.438 kPa, 2 is 0375 kPa, 3 is 0.21 kPa, 4 is 0.11 kPa.

5. Conclusions

It must be noted that the wind load calculation of buildings of complex shapes according to the existing regulations does not provide the required level of operational safety.

It is planned to conduct a series of numerical experiments for the buildings of dome shape for the subsequent development of a mathematical model that will help to improve the accuracy of calculations. Further, it is planned to make adjustments of the existing regulations.

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